EXPERIMENTS

RELATING

TO THE ALLEGED INFLUENCE OF COLOUR

ON THE

RADIATION

OF

NON-LUMINOUS HEAT.

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INQUIRY

In relation to the alleged Influence of Colour on the Radiation of Non-luminous Heat.

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In the following essay I propose to submit a few remarks upon a paper by Doct. Stark of Edinburgh, first published in the Transactions of the Royal Society of London, for 1833, together with an experimental inquiry into the alleged influence of colour on the radiation and absorption of *non-luminous* heat.

The experiments were commenced soon after the paper referred to, reached this country, and in them was adopted what seemed to me the less exceptionable of two methods used by Doctor Stark, which actually bear upon the question of the radiation of non-luminous heat. It was my intention to examine the matter more fully than had been done by Dr. Stark, and to procure a more satisfactory induction by experimenting on a considerable variety of substances. In this I had the kind assistance of my colleague, Prof. Courtenay.

While these experiments were in progress, the remarks of the Rev. Professor Powell, of Oxford, on the paper of Doctor Stark, appeared in the Edinburgh New Philosophical Journal. They confirmed me entirely in the view of the inapplicability of most of the experiments made by Doct. Stark, to the determination of the question of the influence of colour on the radiation or the absorption of heat. Of this class were the absorption of heat, *radiant* heat being understood, as tested by the inverse of Count Rumford's method for comparing the conducting powers of substances used for clothing; also as tested by the effect of the heat from the *flame* of an argand gas burner, thrown by a mirror upon the bulb of an air thermometer, which was variously coated. Of the same class were the experiments on radiation, as tested by the method used by Count Rumford, above referred to; the enveloping materials on the inner thermometer being wools of different colours, and coloured wheaten paste.

Not included in this class were the methods of ascertaining the rate of cooling of a thermometer of which the bulb was coated with different pigments, and of a glass globe filled with warm water and variously coated. I give the preference to a modification of this latter method from the greater extent of radiating surface which may, without inconvenience, be commanded by it. The glass globe used by Dr. Stark, was one inch and a quarter in diameter; it was coated at different times with Prussian blue, red lead, and white lead, and in a room at 50° Fah., the fall of temperature from 120°, through 25 degrees, was with the coatings respectively, in seventeen minutes, eighteen minutes, and nineteen minutes.

I am constrained to differ from Professor Powell in his remarks upon the method just referred to, and, with great deference to so high authority, would state why I consider them inconclusive. Professor Powell deems it necessary, or at least highly important to the determination of the question, that the radiating coatings of the globe should be equalized

in respect to thickness, conducting power, density, &c., and refers to the experiments of Prof. Leslie, in which equal quantities of different radiating substances were dissolved and spread upon a surface, for comparison. That equal thicknesses of substances possessing different radiating powers, should be compared together, seems to me to be disproved by the law established by Sir John Leslie's own experiments, namely, that radiation takes place not only from the surface, but in a thickness which is appreciable in good radiators. This thickness not being the same for different substances. Thus when different coatings of jelly were applied, in succession, upon one of the sides of the cube in Professor Leslie's experiments, the radiation increased with the thickness, up to a certain point. The effect of conducting power appears, by this same experiment, to be so small that an increase of the thickness in the bad conductor was actually more than compensated for by the increased radiating power. The influence of density on conducting power is well known, but the effect of either as controlling the radiating power of a substance, or as modifying it, is, I apprehend, yet to be appreciated. If these views be correct, and they are, I believe, founded upon the authorities so ably illustrated by Professor Powell in his report on radiant heat, to the British Association, the radiating powers of substances would not be rightly compared by equalizing their thicknesses upon a given surface, nor by equalizing their weights; but by ascertaining, for each substance, that thickness beyond which radiation does not take place. This will be placed in a clearer point of view in the sequel.

I do not, however, consider the question at issue as the less difficult to determine; "no substance can be made to assume different colours without at the same time changing its internal structure,"* and I believe with Professor Powell, that "a very extensive induction is perhaps the only means open to us of ascertaining this, (the circumstances and properties wherein the coatings differ) considering how totally ignorant we are of the peculiarities on which their colour depends."

This *very* extensive induction I do not pretend to have made, but I think to have multiplied experiments so much beyond the number made by Dr. Stark, as to be able to show that the supposed influence of colour on the absorption and radiation of heat remains yet to be demonstrated, and thus to prevent the admission as proved of what is more than doubtful.

The principal object was to select a considerable variety of pigments of the same colour differing chemically, and of different colours chemically allied, and, as subsidiary, to ascertain the effect of changes of colour, produced by chemical means, on different substances, and the effect of the material used to apply the pigment to the radiating body.

Several tin cylinders were procured, two inches high, and an inch and a half in diameter, closed at the bottom, and having fitted to the top a slightly conical tube, to receive a perforated cork, through which to pass the stem of a thermometer. One of these vessels having been selected, was coated in successive layers with a pigment. Water which was boiling in a porcelain capsule was then poured into the cylinder, which was suspended by means of two lateral hooks to cords attached to the canopy covering the lecture table. A thermometer introduced through a cork had its bulb nearly in the middle of the axis of the cylinder, and the thermometer by displacing part of the water assured that the quan-

* Prof. Leslie's Essay on Heat.

tity contained was the same in each case. A temperature was selected for beginning the experiments, sufficiently below that which the introduction of boiling water produced, to permit the rate of cooling to have become uniform, and one for ending which was high enough to prevent uncertainty from the slowness of the fall of temperature. The instant of the arrival of the mercurial column at any degree on the scale, and of its leaving the same, was noted, and a mean taken for the time of being at that temperature; a precaution which though superfluous in such experiments as these, will, I am persuaded, be found of importance where minute accuracy is desired in investigating the motion of heat. One of us observed the thermometer, the other noted the time by a pocket chronometer.

The time of cooling of the cylinder coated with colouring matter having been ascertained, an additional layer of the same substance was put upon it and the cooling again observed. The time of cooling diminished, of course, until that thickness was obtained beneath which no radiation takes place, the time then slowly increased with each additional coat, the conducting power entering as an appreciable element into the rate of cooling. To show the decided nature of the results, I subjoin an account of one series towards the beginning of our experiments, when a want of experience rendered us cautious in applying the successive coatings, lest we should pass the thickness of determinate radiation. The necessity for thus feeling our way, rendered the labour of the experiments very considerable.

Cylinder coated with Prussian blue:

Time of cooling from 180° to 140° Fah.

1.	Thick coating, - -	$1011\frac{1}{2}$ seconds.
2.	ditto added, -	965
3.	Additional coat, - -	$910\frac{3}{4}$
4.	do. do. -	$829\frac{1}{2}$
5.	do. do. -	805
6.	do. do. -	824

Another series, in a further advanced stage of our experiments is subjoined:

Cylinder coated with Litmus blue:

Time of cooling from 180° to 140$ Fah.

1.	First thick coating, -	985 seconds.
2.	Additional coat, - -	855
3.	do. do. -	$827\frac{1}{2}$
4.	do. do. - -	$834\frac{1}{2}$

Besides the necessity of making several experiments to obtain a single result, it sometimes occurred that particular results required to be repeated for verification, when apparent discrepancies occurred; this was done to ascertain if they were real or not.

As it was obvious that the experiments must necessarily extend through a considerable time, during which the circumstances attending the cooling of the cylinders could not be expected to remain uniform, a standard for comparison was provided, in a cylinder of which the coating was not changed, and which was observed in regular turn with the other cylinders. At first a vessel without coating was used for this purpose, but as it was found liable to tarnish, it was substituted by a cylinder having a coating of aurum musivum, which was one of the

smoothest and most uniform of the coloured coatings used. The numbers obtained on the different days from a mean of the trials made of the cooling of the standard cylinder, were applied to compare the results of one day with those of another. This assumes that the times of cooling of the different vessels would be affected proportionately by a given change in the circumstances of the experiment. The inability to preserve the circumstances constant is the real objection to this method, and one which most affects the certainty of the results.*

The following example shows the application of this method. The observed times of cooling of the standard cylinder, from 180 to 140° in two experiments on the 31st of October, were $969\frac{1}{2}$ and $968\frac{1}{2}$ seconds, mean 969. Three experiments on the first of November, gave 898, 892, and $893\frac{1}{2}$ seconds, mean $894\frac{1}{2}$.

Cylinder, number four, coated with cochineal, (crimson,) gave for the time of cooling from 180° to 140°, on the 1st of November, $848\frac{1}{2}$. To compare this with a result obtained with the same cylinder, on the 31st of October, we have $894\frac{1}{2} : 969 :: 848\frac{1}{2} : x$, the equivalent number for October 31st, 916.3 seconds.

The results obtained with the same cylinder, on different occasions of experiment, having been thus rendered comparable, the comparison of experiments with different cylinders was effected by determining the time of cooling with the same coating upon different cylinders. Thus, numbers one and two having been coated with carbonate of lead, and their times of cooling through forty degrees having been ascertained, all the results with the various other coatings applied to these cylinders were comparable.

The numbers thus obtained will not be strictly proportional to the radiating power of the substance used, for the whole surface of the cylinders, including the ends, was not coated, and the contact of the air, and its consequent circulation, exert a most important influence on the rate of cooling. This latter element has been shown by the experiments of Petit and Dulong, to be independent of the nature of the surface, and as the amount of uncoated surface remains constant, the greater effect of radiation will appear by the more rapid rate of cooling, and the less by the less rapid rate.

I proceed now to examine the degree of approximation which may be expected from the results of the experiments.

First, a comparison of different observations on the same day, under the same circumstances of the cylinders, and nearly or quite the same as to the temperature of the room, will show how far accuracy is possible under the most favourable suppositions. The following table presents the results of this kind obtained during the entire series of experiments, with the ratios of the times of cooling.

* If the circumstances could be retained the same, three observations of the temperature at equal known intervals, would give a numerical expression for the radiating power of the coating.

Nature of Coating. Cylinder No. 3.	Time in sec's.	Ratio.	Nature of Coating. Cylinder No. 1.	Time in sec's.	Ratio.
No coating.	1281¾	1.000	Sulphuret of Antimony.	849½	1.000
	1300	1.014		972¾	1.145
Chalk.	909¼	1.000	do. additional.	871½	1.000
	939¼	1.034	Coating on another occ'n.	878½	1.008
Prussian blue.	909½	1.000	Red lead.	886½	1.000
	932½	1.025		894½	1.009
Litmus blue.	920½	1.000	do. blackened	911½	1.000
	956	1.038	by sulphuretted hydrogen	924½	1.014

Cylinder No. 5.			Cylinder No. 4.		
Aurum Musivum.	892	1.000	Gamboge	932	1.000
	893½	1.001		942½	1.011
	898	1.007			
				938½	1.000
do. on another	937½	1.000	Chromate of lead.	954½	1.017
occasion.	959	1.023			
				845	1.000
	943½	1.000	Vermilion.	850	1.006
do.	957	1.014			
				740½	1.000
	818	1.000	Sulphate of Baryta.	778	1.051
do.	820½	1.003			
	850	1.000	Cylinder No. 1.		
do.	860	1.012			
	897	1.055	No coating.	1396½	1.000
				1425½	1.020
	851	1.000		1445½	1.035
do.	872½	1.025			
				1313½	1.000
			do. another occasion.	1315½	1.002
			do.	1303	1.000
				1320	1.013

In the foregoing table, ten of the ratios are about 1.01 to 1, six 1.02 to 1, three 1.03 to 1, one 1.04 to 1, and two 1.05 to 1: it is, therefore, fair to infer that the single ratio of 1.14 to 1 results from an error of record, or observation, and the table fully shows, that, *under the same circumstances, the results could readily be reproduced within about two per cent.*

Second. The correction for the altered circumstances of temperature of the room, &c., may be tested by comparing the experiments made with different cylinders, having the same coatings, on different days. In the annexed table is given the various results of this kind furnished throughout the series of experiments. The date is given in the left hand column, and applies to all the results on the same horizontal line with it. A comparison of the numbers in the columns marked ratio, and on the same horizontal lines, will show how far the same reduction to a standard would have been given by different cylinders; in other words, how

far the influence of currents of air, local temperature, and radiation from or to adjacent bodies, might have interfered with the particular results.

Date.	No. of cylind.	Nature of Coating.	Reduced time of cooling.	Ratio.	No. of cylind.	Nature of coating.	Reduced time of cooling.	Ratio.	No. of cylind.	Nature of coating.	Reduced time of cooling.	Ratio.
Oct. 21	II.	Not coated.	1406	1.00	III.	Prussian blue.	914	1.00				
24			1422½	1.00			953¼	1.04				
24		Do.	1422½	1.06		do.	953¼	1.05				
25			1314½	1.00			910¾	1.00				
28	I.	Ammoniacal sulphate of copper,	853½	1.01	V.	No coating.	1342	1.02	V.	Litmus blue.		
29			849½	1.00			1311½	1.00			855	1.00
31			862	1.01			1359½	1.04			827	0.97
31	II.	Ammoniacal sulphate of copper,	930	1.13	IV.	Cochineal.	877½	1.03	V.	Aurum Musivum.	968½	1.08
Nov. 1		(not the same as above.)	826½	1.00			848½	1.00			894½	1.00
1	II.	Ammoniacal sulphate of copper,	808½	1.00	IV.	Chromate of lead.	907	1.00	V.	Aurum Musivum.	894½	1.00
6		(not the same as above.)	831½	1.03			944½	1.04			48½	1.06
6	I.	Red lead.	890½	1.00	IV.	Alkanet.	980½	1.00	V.	Aurum Musivum.	948¼	1.00
11			912¼	1.02			926¾	0.95			950¼	1.00
15	V.	Aurum Musivum.	865½	1.06	VI.	Black lead.	870	1.09				
17			819¼	1.00			799	1.00				
17	III.	India Ink.	788½	1.00	V.	Aurum Musivum.	819½	1.00				
18			836½	1.06			869	1.06				
20		India Ink.	834	1.00	V.		916	1.00				
21			890	1.07			861¾	1.06				

Of the ratios thus brought into comparison, it will be found that, in one case, the results are identical; in four others, that they differ one per cent.; in two others, two per cent.; in four others, three; in one, four; in

three, five; in two, seven; and in one, ten per cent.; omitting this latter, the accordance is much less satisfactory than was shown by the former table, and the average amount of error is nearly four per cent.

Having now shown the probable limits of accuracy in the experiments, I proceed to compare the reduced times of cooling of the same cylinders with different coatings. In the table will be given the observed time of cooling through forty degrees, and the time of cooling of the standard, from whence the reduced times are deduced. As the colours of the substances were not in all cases what would be expected, the colour is designated in a separate column.

Cylinder No. 1, variously coated.

Nature of Coating.	Colour.	Date.	Observed time of cooling.	Time of cooling of standard.	Reduced time of cooling.	Remarks.
			sec'ds.	sec'ds.	sec'ds.	
Carbonate of lead.	White.	Oct. 24	864	1014	864	Smooth.
Vermillion.	Red.	25	806	937	872	Smooth, with minute cracks.
Golden Sulphuret of Antimony	Brown, nearly black.	31	868.5	969	909	Rough, peels easily
Red Oxide of lead.	Orange.	Nov. 6	890 5	948.2	952	Smooth.
do. additional coat.		11	932.7	950.2	995	For comparison with following.
Do. blackened by hydro sulphate of potassa.	Brown.		917.8	"	966	Red shows thro'.
Plumbago.	Black.	17	787	819.2	974	Uniform, but not glossy.
Gamboge.	Olive.	20	808.7	816.	1005	Smooth, but in streaks.

The radiating power being greater, as the time of cooling is less, we have the order of radiating power of the different coloured substances, as follows: white, red, brown, orange, black, green; omitting in this enumeration the blackened surface of the red oxide of lead, which had passed in thickness the maximum radiating thickness, and is only comparable with the result which precedes it. The change effected by altering the surface to sulphuret of lead, (black, or rather brown,) appears to increase the radiating power in the ratio of 1.03 to 1, which is, however, within the average of error.

The following results, given in order of time, and reduced by the standard, were obtained with cylinder No. 2.

Nature of coating.	Colour.	Date.	Observed time of cooling. sec'ds.	Time of cooling of standard. sec'ds.	Reduced time of cooling. sec's	Remarks.
Ammoniacal sulphate of copper.	Blueish green.	Nov. 6	808.5	948.2	856	Streaked and peels off, rough.
Indigo.	Blue.	11	928.	950.2	990	Very smooth.
Carbonate of lead.	White.	14	883.2	956.	937	Smooth.
do.		15	910	856.5	982	For comparison with following.
do. blackened by hydro sulphate of potassa.	Black.	15	874		944	
Per oxide of Manganese.	Darkbrown	18	747	869	872	Uniform but not smooth.

The variety of colour is here small; the radiating powers rank, blueish green, dark brown, white, blue; omitting the second experiment with the carbonate of lead, which is only comparable with the one in which the surface was blackened by hydro-sulphate of potassa. Comparing these two results, the change of surface appears to have increased the radiating power in the ratio of 1.04 to 1. The coatings applied to cylinder No. 3 were more varied than those of either of the foregoing.

Cylinder No. 3.

Nature of coating.	Colour.	Date.	Observed time of cooling. sec'ds.	Time of cooling of standard. sec'ds.	Reduced time of cooling. sec's	Remarks.
Carb. of magnesia.	Yellowish white.	Oct. 11	859.5	862	1011	Rough, in specks projecting.
Carbonate of lime, (chalk)	White.		879		1034	do.
Carbonate of lead.	White.		877		1032	Smooth and somewhat shining.
Prussian blue.	Blue.	25	805	937	871	Rough.
Litmus.	Blue.	31	831	969	870	Not uniform.
Bichromate potassa	Reddish brown.	Nov. 1	854	894.5	986	Streaked and not smooth.
Alkanet.	Crimson.	11	926.7	950	989	Uniform.
Do. rendered blue by potassa.	Blue.		938.2		1001	
India ink.	Black.	17	776	819	959	Not smooth,
do.		18	836	869	976	More uniform, (mean 967)
Carbonate of lead in oil of lavender.	White.	21	843.5	862	992	Uniform, but not glossy on surface.
Do. blackened by hydro sulphate of potassa.	Black.		850		1000	

The effect of changing the crimson of alkanet to a blue, was, apparently, to decrease its radiating power about one per cent., or the change of colour in reality did not alter the power. The carbonate of lead lost also slightly, or rather was not affected, by the change, not only of its surface, but of a considerable part of its mass, for the oil of lavender having evaporated, the hydro-sulphate of potassa penetrated the coating. The substance by means of which the coating was applied, seems not to have sensibly affected the radiating power; the carbonate of lead, applied with gum differing in radiating power but four per cent. from that applied with oil of lavender.

The colours rank from the foregoing table, blue, two varieties; black, brown, crimson, white, black, blue, white, three varieties. There is no certainty that the litmus and the alkanet changed to blue by potassa, were originally the same in colour. The surfaces were very different in regard to uniformity and smoothness; the alkanet was perfectly uniform, but not at all glistening; it may be described as of a uniformly minute roughness. In this table, we have the greater number of whites at the bottom of the scale of radiation, and of blues and blacks at the top; but this is all that can be said, for a white, a black, and a blue, are in close proximity near the middle of the scale.

The results, with cylinders Nos. 4 and 5, were few in number. They are subjoined.

Cylinder, No. 4.						
Cochineal,	Crimson,	Nov. 1	848.5	894.5	962	Not uniform,
Chromate of lead,	Yellow,	6	931.7	948.5	996	Very smooth and uniform.
Bi sulph't. of mercury, (vermilion)	Red,	11	843.7	950.2	888	Uniform and smooth.
Sulphate of baryta,	White,	15	759.2	865.2	889	Rough.
Ditto,	"	21	829	861.7	975	Smooth, freshly precipitated.
Cylinder, No. 5.						
Gamboge,	Olive,	Oct. 29	845.5	934	917	Smooth.
Bi-sulphuret of tin, (aurum musivum,)	Yellow,	31	969	969	1014	Very even.

The order from cylinder No. 4, is red, white, crimson, white, yellow; the influence of the roughness of surface is here plainly shown, by which the place of the white material, sulphate of baryta, is entirely changed; this is a quality difficult to appreciate, and yet here we find it exceeding in influence any other property of the coating.

A review of these results will show that we have been able to establish, among the separate series, no order of colour; we have the different orders as follows.

From No. 1.	No. 2.	No. 3.	No. 4.
White,	Green,	Blue,	Red,
Red,	Brown,	Black,	White,
Brown,	White,	Brown,	Crimson,
Orange,	Blue,	Crimson,	White,
Black,	White to black, an increase of 4 per cent. in radiating power.	White,	Yellow.
Green,		Black,	No. 5.
White to black, an increase of 3 per cent. in radiating power.		White,	Green,
		No effect from changing white to bl'k, or purple to blue.	Yellow.

A more satisfactory comparison, in respect to the number of substances employed, will be had by using the means, heretofore described, for comparing together the results obtained with different cylinders. For example, Nos. 1, 2, and 3, were each coated with carbonate of lead, and through the numbers given by these coatings, those found for the other coatings can be compared; Nos. 1 and 4 were coated with vermillion, and Nos. 1 and 5 with gamboge.

The following table presents the comparison, the substances being arranged in the order of their radiating powers.

Number.	Nature of coating.	Colour.	Number of Cylinders.	Date.	Time of Cooling. sec'ds.	Remarks on Surface.
1	Litmus blue,	Blue	No.3	Oct. 31	728	
2	Prussian blue,	Blue	3	25	729	Rough.
3	Ammoniacal Sulphate of copper.	Greenish blue	2	Nov. 6	789	Rough.
4	Per-oxide of manganese,	Brownish bl'k	2	18	804	Not shining, but uniform.
5	India ink,	Black	3	17	804	Not smooth.
6	Bi-chromate of potassa,	Brown	3	1	810	Streaked, streaks smooth.
7	India ink,	Black	3	18	817	Smooth.
8	Alkanet,	Crimson	3	11	828	Not shining, but uniform.
9	Carbonate of lead in oil of lavender	White	3	21	830	Smooth, not shin'g
10	Sulphuret of lead,	Black	3	21	837	
11	Alkanet blue,	Blue	3	11	838	
12	Carbonate of magnesia,	White	3	Oct. 13	846	Rough.
13	Carbonate of lead in gum.	White	1	24	864	Smooth.
14	Carbonate of lime,	Dingy white	3	11	865	Medium.
15	Vermilion,	Red	1	25	872	Smooth.
16	Sulphate of baryta,	White	4	Nov. 15	873	Rough, blueish white.
17	Golden sulphuret of antimony,	Brown	1	Oct. 31	909	Smooth, in streaks.
18	Indigo,	Blue	2	Nov. 11	912	Smooth.
19	Cochineal,	Crimson	4	1	944	Smooth.
20	Red lead,	Orange	1	6	952	Smooth.
21	Sulphate of baryta,	White	4	21	957	Medium.
22	Plumbago,	Black	1	17	974	Not shining, but uniform.
23	Chromate of lead,	Yellow	4	6	977	Smooth.
24	Gamboge,	Olive green	1	20	1005	Smooth, in streaks
25	Bi-sulphuret of tin,	Yellow	5	Oct. 31	1085	Smooth.

The results thus exhibited are decidedly unfavourable to the specific effect of colour in determining the radiating powers of bodies. Blue is above black at the beginning of the table, and occurs again in the eighteenth place. Although the first seven numbers are blue, or black, the ninth, tenth, eleventh, and twelfth, are white, black, blue, and white,

respectively. Red occupies the eighth and nineteenth places, and then an intermediate one, namely, the fifteenth. White is in the greater number of cases in the middle part of the table, ranging close to black.

The alleged advantages of dark clothing during cold weather, thus seems to have been too hastily inferred; and it appears that, provided the person is not exposed to the sun, the particular colour of the clothing is not of real importance.

If colour is not a determining quality, neither does roughness appear to be so, for though generally the smooth surfaces are lower on the list, this is not universal. The rough sulphate of baryta is lower on the list than the smooth carbonate of lead. Plumbago occupies a low place, and India ink a comparatively high one.

The best radiators do not appear to belong to any particular class of bodies; litmus blue and Prussian blue are side by side, while sulphuret of lead, and the bi-sulphuret of tin are fifteen numbers apart.

If the results be admitted as decisive of the radiating powers of the bodies used they show that each substance has a specific power not depending upon chemical composition, nor upon colour. I do not claim to found such a conclusion upon the experiments; their object has been before stated, and if they shall prevent the introduction of an inference from an imperfect induction, as a law of science, the labour bestowed upon them will be amply recompensed.*

* The scientific reader need not be reminded that these remarks do not bear upon the radiation or absorption of heat accompanying light.